CHAPTER 2

PRINCIPLES OF AN INTERNAL COMBUSTION ENGINE

LEARNING OBJECTIVE: *Explain the principles of operation, the different classifications, and the measurements and performance standards of an internal combustion engine.*

As a Construction Mechanic, you are concerned with repairing and replacing worn or broken parts, making various adjustments to vehicles and equipment, and ensuring that they are serviced properly and inspected regularly. To perform these duties intelligently, you must fully understand the operation and function of the various components of an internal combustion engine. This makes your job of diagnosing and correcting troubles much easier. This, in turn, saves time, effort, and money.

This topic discusses the theory and operation of an internal combustion engine. You also need to become familiar with the terms being used.

INTERNAL COMBUSTION ENGINE

LEARNING OBJECTIVE: *Identify the series of events, as they occur, in both a gasoline engine and a diesel engine. Describe the differences between a four-stroke cycle engine and a two-stroke cycle engine.*

Combustion is the act or process of burning. An "external" or "internal" combustion engine is defined simply as a machine that converts heat energy into mechanical energy. Figure 2-1 shows, in simplified form, an external and an internal combustion engine.

In the internal combustion engine, combustion takes place inside the cylinder and is directly responsible for forcing the piston to move down. With an external combustion engine, such as a steam engine, combustion takes place outside the engine. The external combustion engine requires a boiler to which heat is applied. This combustion causes water to boil to produce steam. The steam passes into the cylinder under pressure and forces the piston to move downward.

The transformation of **HEAT ENERGY** to **MECHANICAL ENERGY** by the engine is based on the fundamental law of physics which states that gas expands when heated. The law also states that when gas is compressed, the temperature of the gas increases. if the gas is confined with no outlet for expansion, then the pressure of the gas increases when heat is applied. In the internal combustion engine, the burning of fuel within an enclosed cylinder results in an expansion of gases. This expansion creates pressure on top of the piston, causing it to move downward. In an internal combustion engine, the piston moves up and down

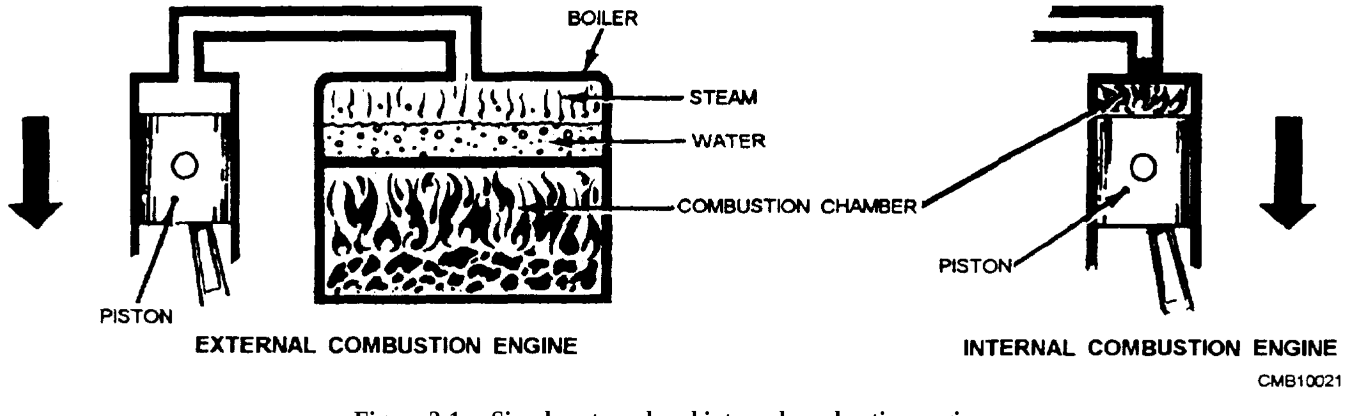


Figure 2-1.—Simple external and internal combustion engines.

within the cylinder. The relationship between volume, pressure, and temperature within a cylinder of the engine is explained in the chart below and shown in figure 2-2. Note the changes within the cylinder while the temperature outside remains a constant 70°F.

View	Description
A and B	The piston moves upward, compressing the air in the cylinder.
B and C	As **volume** decreases, **pressure** increases, and **temperature** rises. These changing conditions continue, as the piston moves upward.
D	As the piston nears TDC, **volume is still decreasing.** Because of compression within the cylinder, both **pressure and temperature of the air are now greater** than at the beginning.

This up-and-down motion is known as **RECIPROCATING MOTION.** This motion (straight-line motion) must be changed into **ROTARY MOTION** (turning motion) to turn the wheels of a vehicle. A crankshaft and a connecting rod change their reciprocating motion to rotary motion.

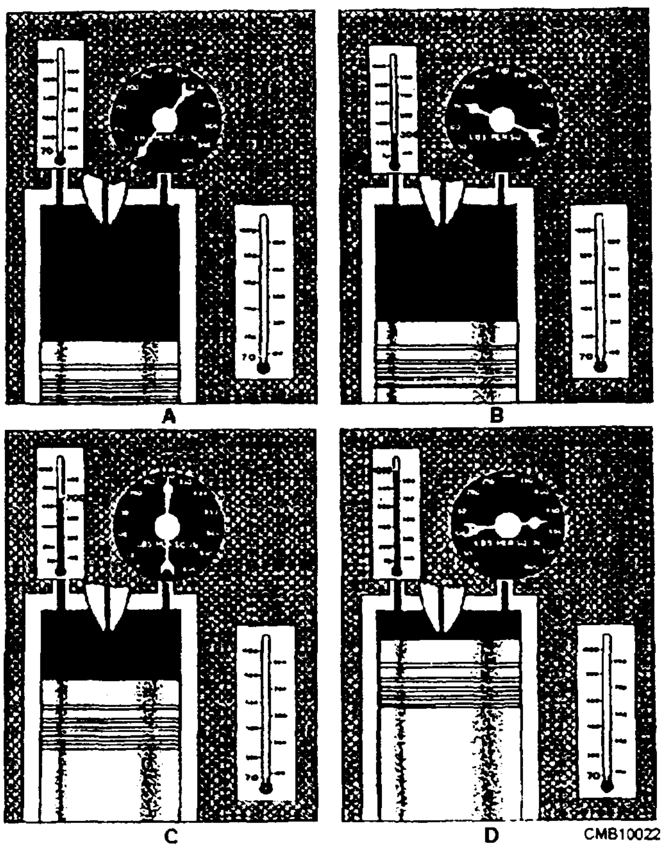


Figure 2-2.—Volume, pressure, and temperature relationships.

All internal combustion engines, whether gasoline or diesel, are basically the same. We can best demonstrate this by saying they all rely on three **things—FUEL, AIR,** and **IGNITION.**

FUEL contains potential energy for operating the engine; **AIR** contains the oxygen necessary for combustion; and **IGNITION** starts combustion. Each one is fundamental, and an engine cannot operate without them. Any discussion of engines must be based on these three factors and the steps and mechanisms involved in delivering them to the combustion chamber at the proper time.

DEVELOPMENT OF POWER

The power of an internal combustion engine comes from burning a mixture of fuel and air in a small, enclosed space. When this mixture bums, it expands greatly, and the push or pressure created is used to move the piston, thereby rotating the crankshaft. This motion is eventually sent to the wheels that move the vehicle.

Since similar action occurs in each cylinder of an engine, let's use one cylinder to describe the steps in the development of power. The one-cylinder engine consists of four basic parts, as shown in figure 2-3.

First, we must have a CYLINDER that is closed at one end; this cylinder is similar to a tall metal can that is stationary within the engine block.

Inside this cylinder is the PISTON—a movable plug. It fits snugly into the cylinder but can still slide up and down easily. This piston movement is caused by fuel burning in the cylinder and results in production of reciprocating motion.

You have already learned that the up-and-down movement of the piston is called reciprocating motion. This motion must be changed into rotary motion, so the wheels or tracks of a vehicle can rotate. This change is accomplished by a throw on the CRANKSHAFT and the CONNECTING ROD which connects the piston and crankshaft throw.

The throw is an offset section of the crankshaft that scribes a circle, as the shaft rotates. The top end of the connecting rod is connected to the piston and must therefore go up and down. The lower end of the connecting rod is attached to the Crankshaft. The lower end of the connecting rod also, moves up and down but,

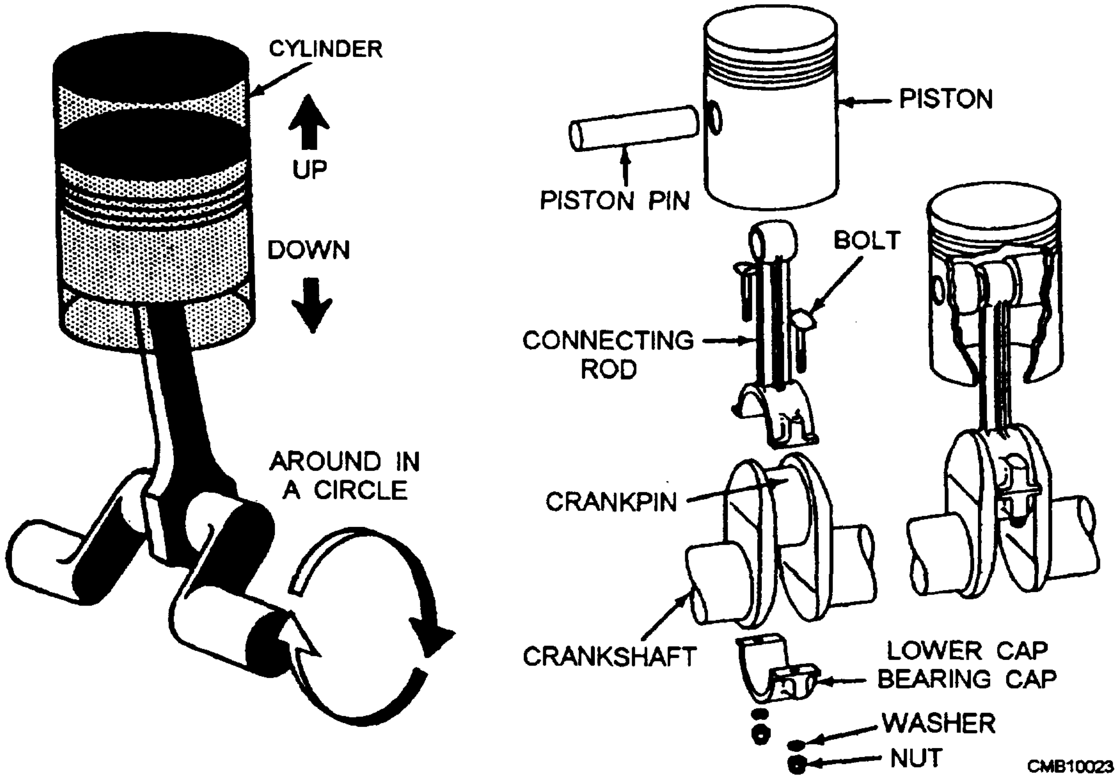


Figure 2-3.—Cylinder, piston, connecting rod, and crankshaft for a one-cylinder engine.

because it is attached to the crankshaft, it must also move in a circle.

When the piston of the engine slides downward because of the pressure of the expanding gases in the cylinder, the upper end of the connecting rod moves downward with the piston in a straight line. The lower end of the connecting rod moves down and in a circular motion at the same time. This moves the throw and, in turn, the throw rotates the crankshaft; this rotation is the desired result. So remember, the crankshaft and connecting rod combination is a mechanism for the purpose of changing straight line, or reciprocating motion to circular, or rotary motion.

FOUR-STROKE-CYCLE ENGINE

Each movement of the piston from top to bottom or from bottom to top is called a stroke. The piston takes two strokes (an up stroke and a down stroke), as the crankshaft makes one complete revolution Figure 2-4

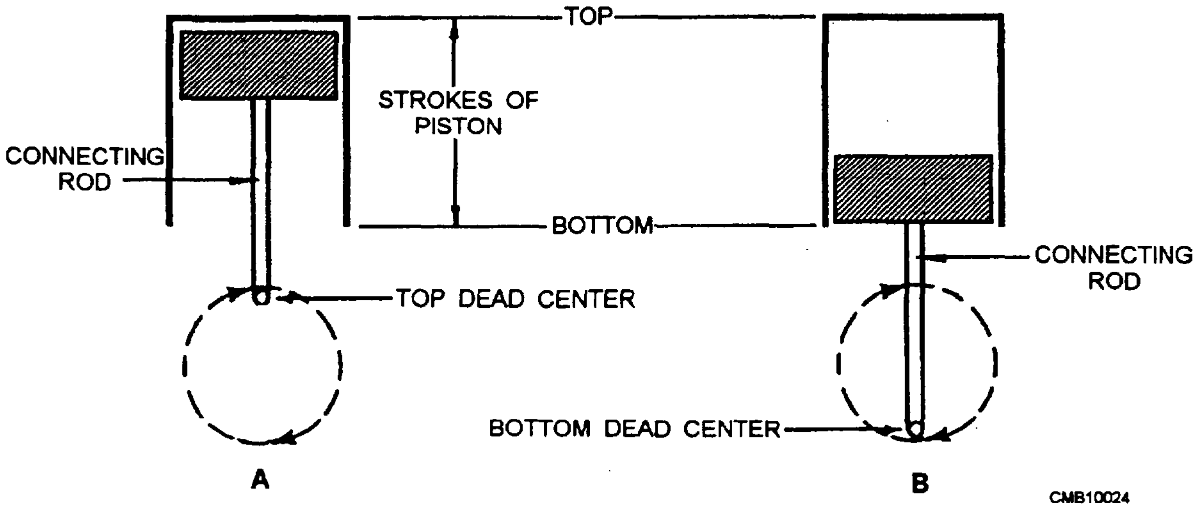


Figure 2-4.—Piston stroke technology.

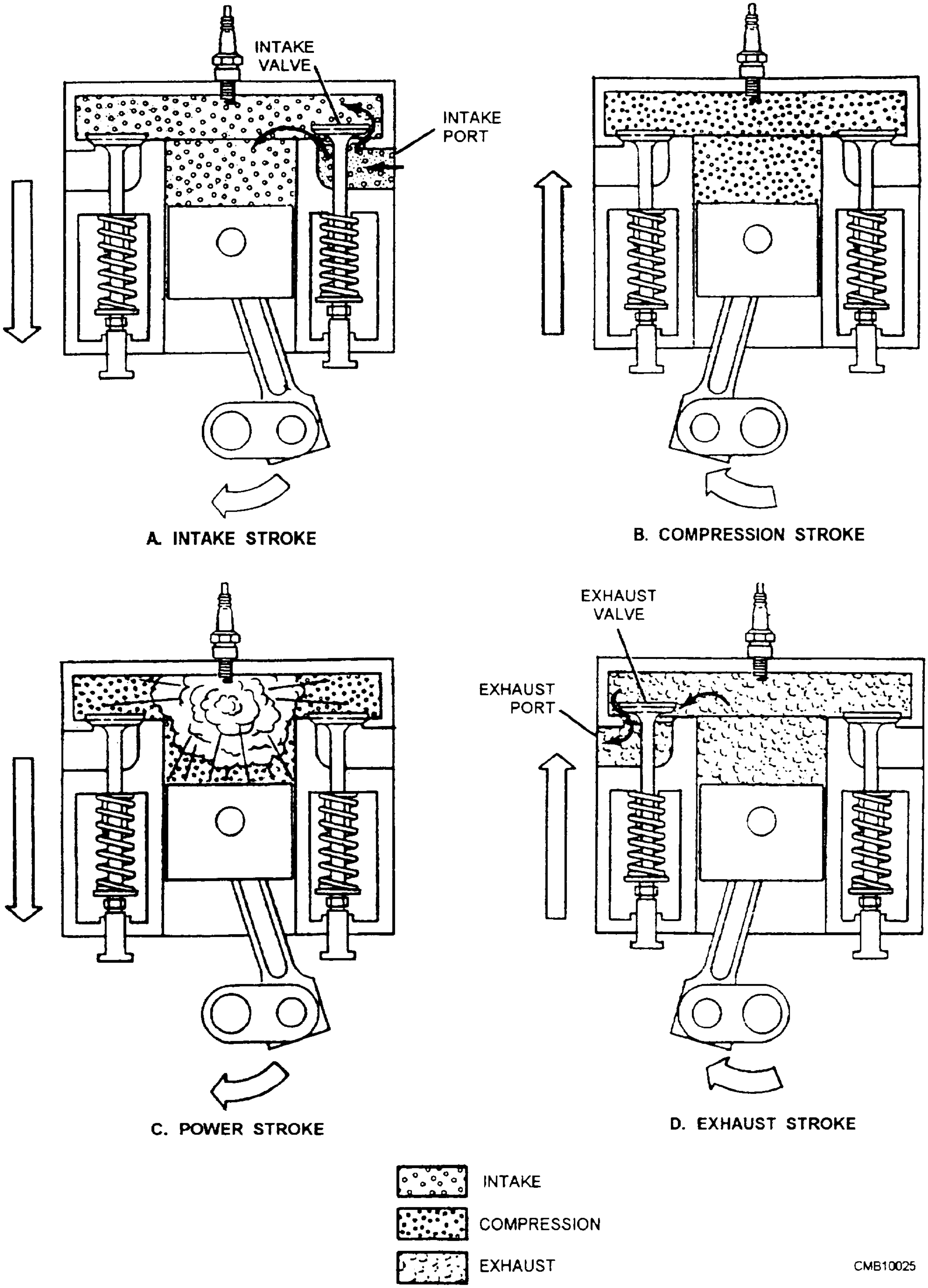


Figure 2-5.—Four-stroke cycle in a gasoline engine.

shows the motion of a piston in its cylinder. The piston is connected to the rotating crankshaft by a connecting rod. In view A of figure 2-4, the piston is at the beginning or top of the stroke. As the crankshaft rotates, the connecting rod pulls the piston down. When the crankshaft has rotated one-half turn, the piston is at the bottom of the stroke. Now look at view B of figure 2-4. As the crankshaft continues to rotate, the connecting rod begins to push the piston up. The position of the piston at the instant its motion changes from down to up is known as **bottom dead center (BDC).** The piston continues moving upward until the motion of the crankshaft causes it to begin moving down. This position of the piston at the instant its motion changes from up to down is known as **top dead center (TDC).** The term *dead* indicates where one motion has stopped (the piston has reached the end of the stroke) and its opposite turning motion is ready to start. These positions are called **rock** positions and discussed later under "Timing."

The following paragraphs provide a simplified explanation of the action within the cylinder of a four-stroke-cycle gasoline engine. It is referred to as a four-stroke cycle because it requires four complete strokes of the piston to complete one engine cycle. Later a two-stroke-cycle engine is discussed. The action of a four-stroke-cycle engine may be divided into four parts: the intake stroke, the compression stroke, the power stroke, and the exhaust stroke.

Intake Stroke

The first stroke in the sequence is called the **INTAKE** stroke (figs. 2-5 and 2-6). During this stroke, the piston is moving downward and the intake valve is open. This downward movement of the piston produces a partial vacuum in the cylinder, and the air-fuel mixture rushes into the cylinder past the open intake valve. This is somewhat the same effect as when you drink through a straw. A partial vacuum is produced in the mouth and the liquid moves up through the straw to fill the vacuum.

Compression Stroke

When the piston reaches bottom dead center (BDC) at the end of the intake stroke and is therefore at the bottom of the cylinder, the intake valve closes. This seals the upper end of the cylinder. As the crankshaft continues to rotate, it pushes up through the connecting rod on the piston. The piston is therefore pushed upward and compresses the combustible mixture in the cylinder; this is called the **COMPRESSION** stroke (figs. 2-5 and 2-6). In gasoline engines, the mixture is compressed to about one eighth of its original volume; this is called 8 to 1 compression ratio. This compression of the air-fuel mixture increases the pressure within the cylinder. Compressing the mixture makes it even more combustible; not only does the pressure in the cylinder increase, but the temperature of the mixture also increases.

Power Stroke

As the piston reaches top dead center (TDC) at the end of the compression stroke and therefore has moved to the top of the cylinder, the compressed air-fuel mixture is ignited. The ignition system causes an electric spark to occur suddenly in the cylinder, and the spark ignites the air-fuel mixture. In burning, the mixture gets very hot and tries to expand in all directions. The pressure rises between 600 to 700 pounds per square inch. Since the piston is the only thing that can move, the force produced by the expanded gases forces the piston down. This force, or thrust, is carried through the connecting rod to the crankshaft throw on the crankshaft. The crankshaft is given a powerful push This is called the **POWER** stroke (figs. 2-5 and 2-6). This turning effort, rapidly repeated in the engine and carried through gears and shafts, turns the wheels of a vehicle and causes it to move.

Exhaust Stroke

After the air-fuel mixture has burned, it must be cleared from the cylinder. This is done by opening the exhaust valve just as the power stroke is finished, and the piston starts back up on the **EXHAUST** stroke (figs. 2-5 and 2-6). The piston forces the burned gases out of the cylinder past the open exhaust valve.

TWO-STROKE-CYCLE ENGINE

In the two-stroke-cycle engine (fig. 2-7), the same four events (intake, compression, power, and exhaust) take place in only two strokes of the piston and one complete revolution of the crankshaft. The two piston strokes are the compression stroke (upward stroke of the piston) and power stroke (the downward stroke of the piston). Remember that a diesel engine has six events that must happen to complete a cycle of operation. To better understand the cycle of operation that happens inside the cylinders of a two-stroke diesel engine, refer to the chart below while reviewing figure 2-7.

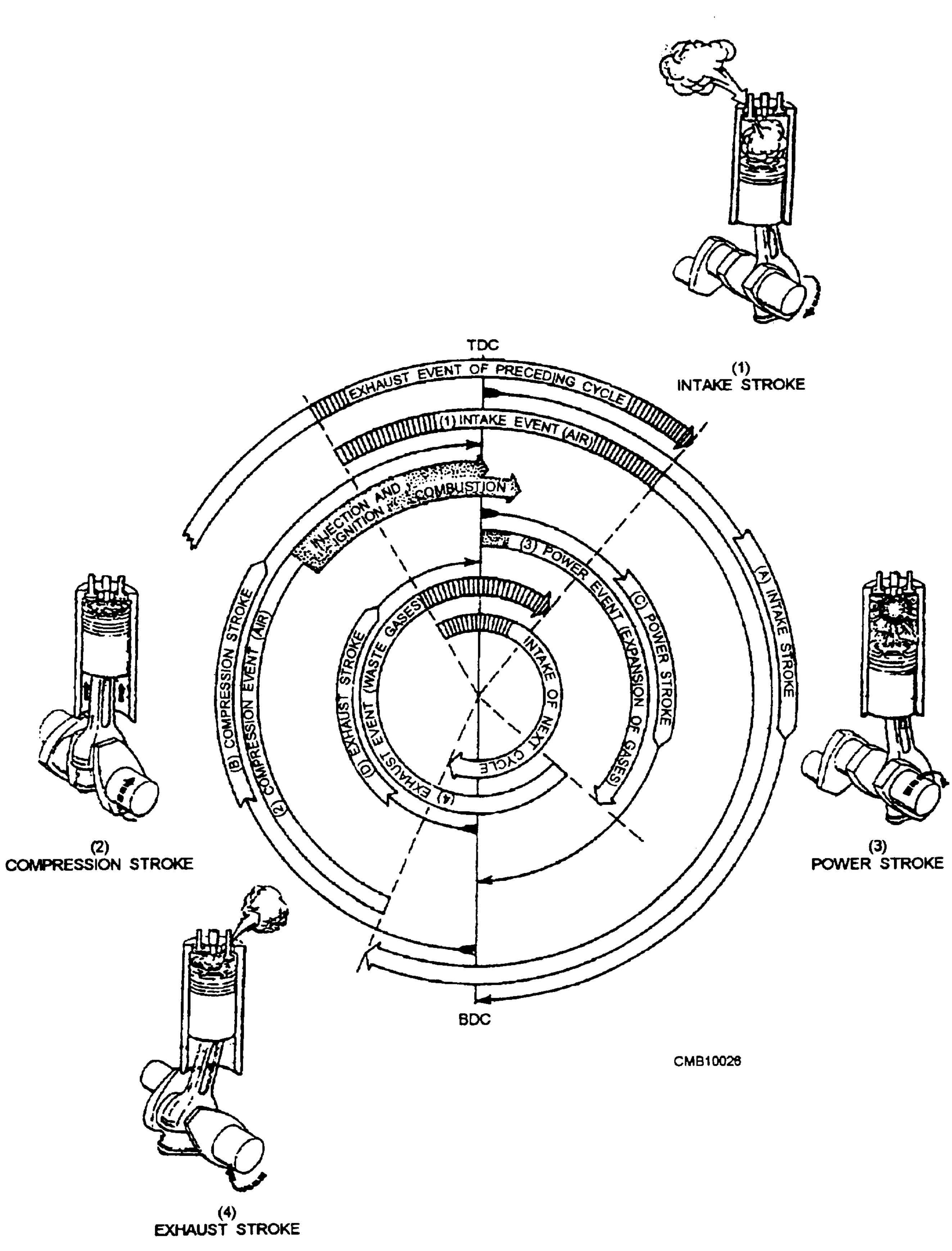


Figure 2-6.—Strokes and events in a four-stroke-cycle diesel engine.

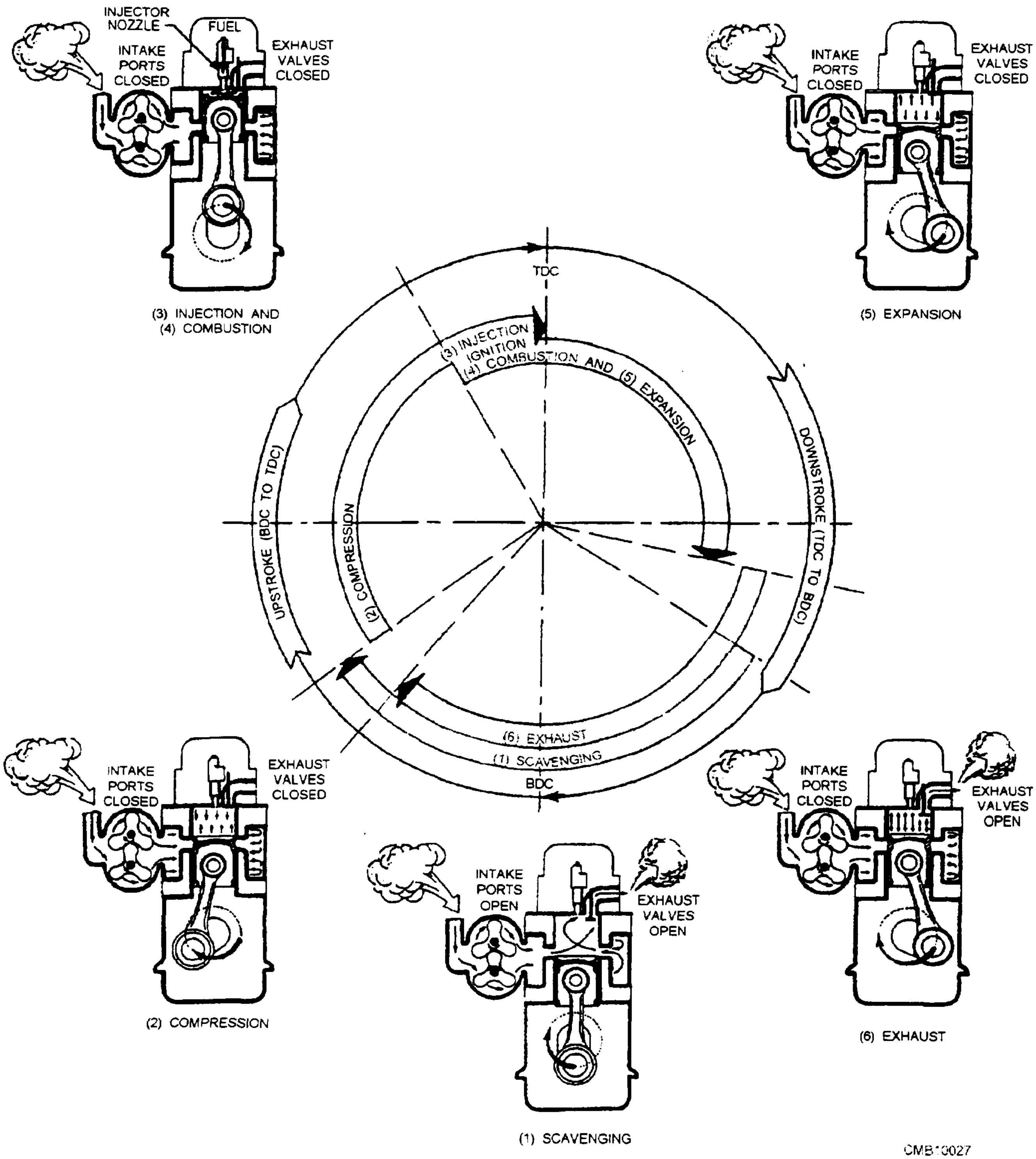


Figure 2-7.—Strokes and events in a two-stroke-cycle diesel engine cylinder.

Sequence of events	Description of Events
(1) Scavenging (intake)	A fresh change of air is forced into the cylinder intake **ports** by the blower. Exhaust gases escape through the open exhaust **valves.**
(2) Compression	As the piston moves upward, the intake ports are covered and the exhaust valves close. The air is compressed in the cylinder; the piston continues to move towards TDC.
(3) Injection/ignition and (4) Combustion	When the piston nears the top of its stroke, fuel is injected into the cylinder. The fuel ignites due to the heat of compression.
(5) Expansion (power)	The rapid expansion of burning gases forces the piston down.
(6) Exhaust	As the piston nears BDC, the exhaust valves open, starting the release of exhaust.

As shown earlier, a power stroke is produced every crankshaft revolution within the two-stroke-cycle engine, whereas the four-stroke-cycle engine requires two revolutions for one power stroke. It might appear then that the two-stroke-cycle engine can produce twice as much power as the four-stroke-cycle engine of the same size, operating at the same speed; however, this power increase is limited to approximately 70 to 80 percent because some of the power is used to drive a blower that forces the air charge into the cylinder under pressure. Also, the burned gases are not completely cleared from the cylinder, reducing combustion efficiency. Additionally, because of the much shorter period the intake port is open (compared to the period the intake valve in a four stroke is open), a relatively smaller amount of air is admitted. Hence, with less air, less power per stroke is produced in a two-stroke-cycle engine.

You need to know the differences between a two-stroke and four-stroke engine. Study the following chart.

TWO-STROKE	FOUR-STROKE
1. One cycle equals one crankshaft revolution and two piston strokes.	1. One cycle equals two crankshaft revolutions and four piston strokes.
2. Requires a blower.	2. Blower is optional.
3. Requires intake and exhaust ports or intake ports and exhaust valves.	3. Requires only intake and exhaust valves.

Figure 2-8 shows a comparison of events that occur during the same length of time for both two-stroke- and four-stroke-cycle engines. Notice the shaded areas that represent the overlapping of events.

Q1. For a vehicle to move, reciprocating motion must be changed to what type of motion?

Q2. On what three things must an internal combustion engine rely to operate ?

Q3. A one-cylinder engine consists of what number of parts?

Q4. A two-stroke engine has approximately what percentage of power increase over a four-stroke engine?

Q5. In a two-stroke diesel engine, what sequence of events happens during the intake stroke?

CLASSIFICATION OF ENGINES

LEARNING OBJECTIVE: *Recognize the differences in the types, the cylinder arrangements, and the valve arrangements of internal combustion engines.*

Engines for automotive and construction equipment may be classified in a number of ways: type of fuel used, type of cooling used, or valve and cylinder arrangement. They all operate on the internal combustion principle, and the application of basic principles of construction to particular needs or systems of manufacture has caused certain designs to be recognized as conventional.

The most common method of classification is by the type of fuel used; that is, whether the engine burns gasoline or diesel fuel.

ENGINE COMPARISON

Mechanically and in overall appearance, gasoline and diesel engines resemble one another; however, in

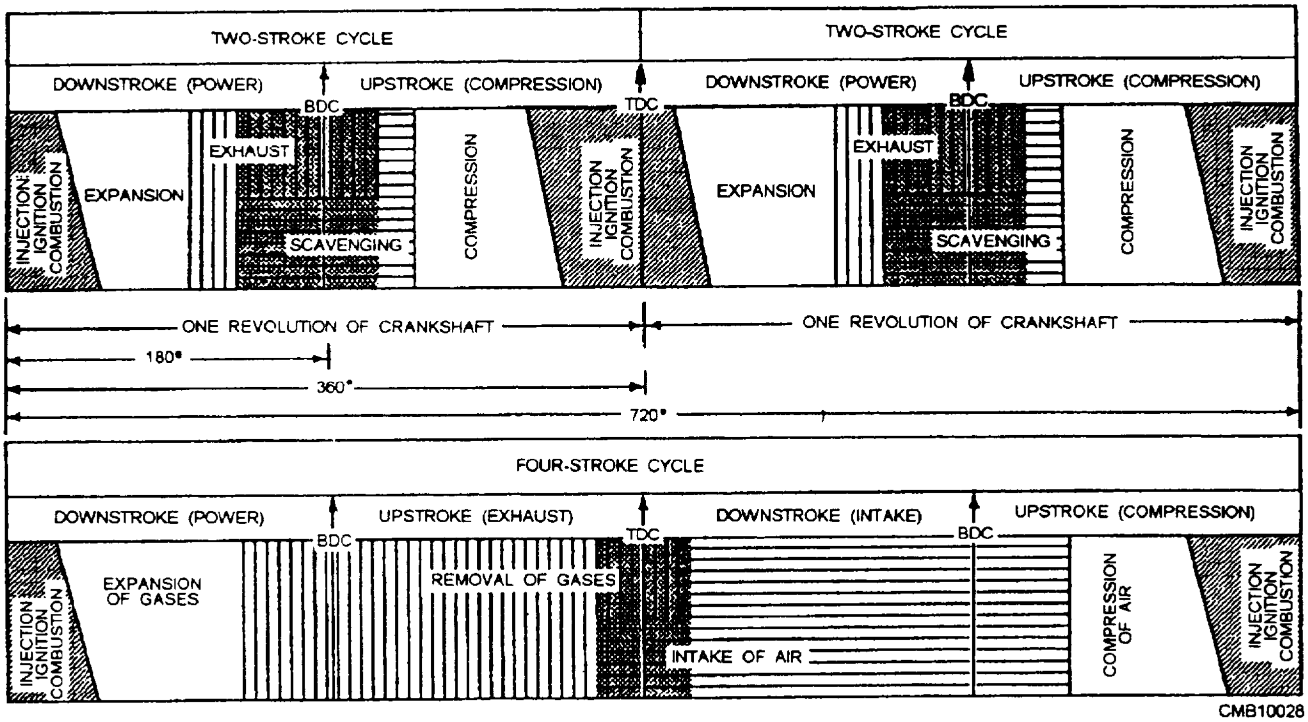


Figure 2-8.—Comparison of two-stroke and four-stroke cycles.

the diesel engine, many parts are somewhat heavier and stronger, so they can withstand higher temperatures and pressures that the engine generates. The engines differ also in the type of fuel used and how the air-fuel mixture is ignited. In a gasoline engine, the air and fuel are mixed together in a carburetor or fuel injection system. After this mixture is compressed in the cylinders, it is ignited by an electrical spark from the spark plugs.

A diesel engine has no carburetor. Air alone enters the cylinder where ii is compressed and reaches a high temperature due to compression. The heat of compression ignites the fuel injected into the cylinder and causes the air-fuel mixture to burn. A diesel engine requires no spark plugs; the contact of diesel fuel with hot air in the cylinders causes ignition. In a gasoline engine, the heat from compression is not enough to ignite the air-fuel mixture, so spark plugs are required.

MULTIPLE-CYLINDER ENGINES

The discussion so far has been on a single cylinder engine. A single cylinder provides one power impulse every two crankshaft revolutions in a four-stroke-cycle engine and is delivering power only one fourth of the time. To provide for a more continuous flow of power, modem engines use four, six, eight. or more cylinders. The same series of cycles discussed previously take place in each cylinder.

In a four-stroke cycle, six-cylinder engine, for example, the throws on the crankshaft are set 120 degrees apart, the throws for cylinders 1 and 6, 2 and 5, 3 and 4 being in line with each other (fig. 2-9). The cylinders fire or deliver power strokes in the following order: l-5-3-6-2-4. The power strokes follow each other so closely that there is a fairly continuous and even delivery of power to the crankshaft.

Even so, additional leveling off of the power impulses is desirable, so the engine runs more smoothly. A flywheel (fig. 2-9) is used to achieve this result.

To understand how the flywheel functions, let’s consider a single cylinder engine. It is delivering power only one fourth of the time during the power stroke.

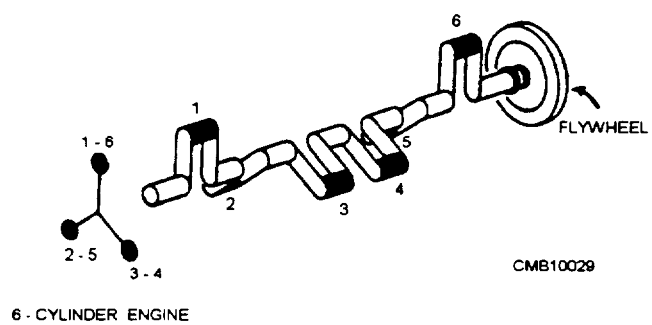


Figure 2-9.—Crankshaft for a sixcylinder engine.

During the other three strokes, it is absorbing power to push out the exhaust gas, to pull in a fresh charge, and to compress the charge. The flywheel makes the engine run without varying much of the speed during each revolution. It is a heavy steel wheel, attached to the end of the crankshaft. When it is rotating, considerable effort is required to slow it down or stop it. Although the wheel does slow down somewhat as it delivers power to the engine during the exhaust, intake, and compression strokes, the wheel speed increases during the power stroke. In effect, the flywheel absorbs some of the engine power during the power stroke and then provides it back to the engine during the other three strokes.

In a multi-cylinder engine, the flywheel functions in a similar manner. It absorbs power when the engine tends to speed up during the power stroke, and it provides power to the engine when the engine tends to slow down during intervals when little power is being delivered by the engine.

In addition to the engine itself, which is the power producer, there must be accessory systems to provide the engine with other requirements necessary to operate it. These systems are the fuel system, the lubrication system, the electrical system, the cooling system, and the exhaust system

ARRANGEMENT OF CYLINDERS

Engines are also classified according to the arrangement of the cylinders (fig. 2-10): **IN-LINE** with all cylinders cast in a straight line above the crankshaft; **V-TYPE** with two banks of cylinders mounted in a V-shape above the crankshaft; **HORIZONTAL OPPOSED** with cylinders arranged 180 degrees from other with opposing cylinders sharing a common crankshaft journal; and **RADIAL** with the cylinders placed in a circle around the crankshaft

- **IN-LINE**—In-line is a common arrangement for both automotive and truck applications. It is commonly built in four- and six-cylinder configurations.
- **V-TYPE**—V-type is also a common arrangement for both automotive and truck applications. The V-type engine in a six-cylinder configuration is suitable for front-wheel drive cars where the engine is mounted transversely.

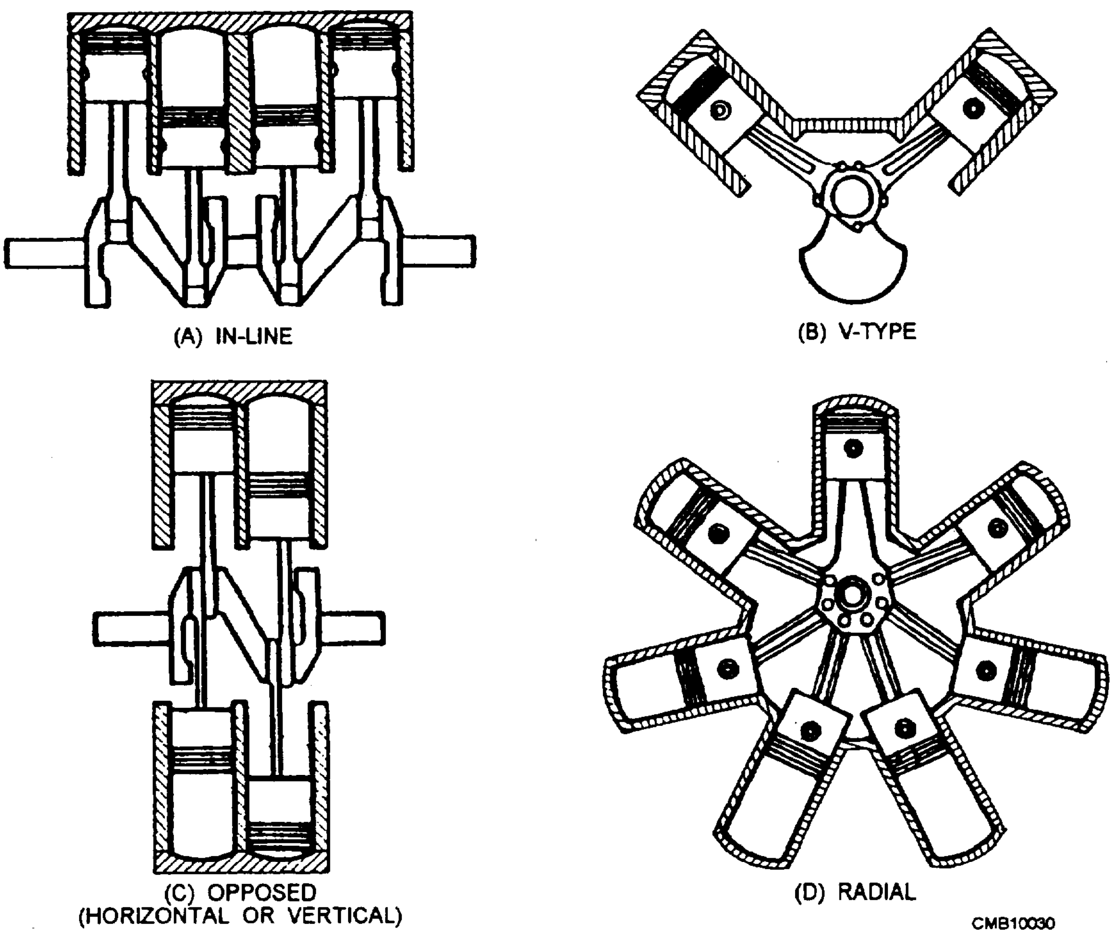


Figure 2-10.—Typical cylinder arrangements

- **HORIZONTAL OPPOSED**—This engine is designed to fit into compartments where height is a consideration. It is used for air-cooled configurations.

- **RADIAL**—This engine is designed almost exclusively for an aircraft engine.

The cylinders are numbered. The cylinder nearest the front of an in-line engine is number 1. The others are numbered 2, 3, 4, and so on, from front to rear. In V-type engines, the numbering sequence varies by manufacturer. You should always consult the manufacturer's manual for the correct order.

The **FIRING ORDER** (which is different from the **NUMBERING ORDER)** of the cylinders of most engines is stamped on the cylinder block or on the manufacturer's nameplate. If you are unable to locate the firing order and no operation or instruction manual is available, turn the engine over by the crankshaft and watch the order in which the intake valves open.

ARRANGEMENT OF VALVES

The majority of internal combustion engines also are classified according to the position and arrangement of the intake and exhaust valves, whether the valves are located in the cylinder head or cylinder block. The following are types of valve arrangements with which you may come in contact:

- **L-HEAD** (fig. 2-11)—The intake and the exhaust valves are both located on the same side of the piston and cylinder. The valve operating mechanism is located directly below the valves, and one camshaft actuates both the intake and the exhaust valves.

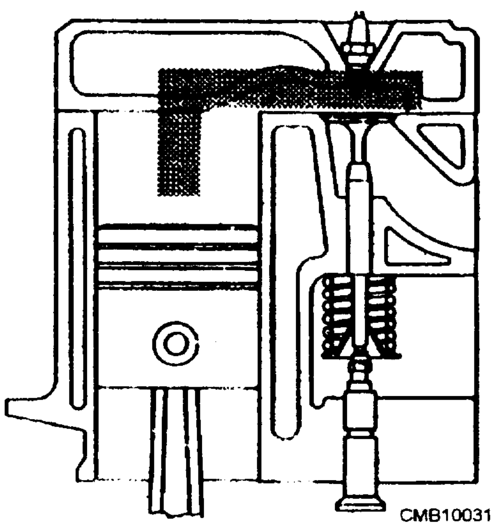


Figure 2-11.—L-head engine.

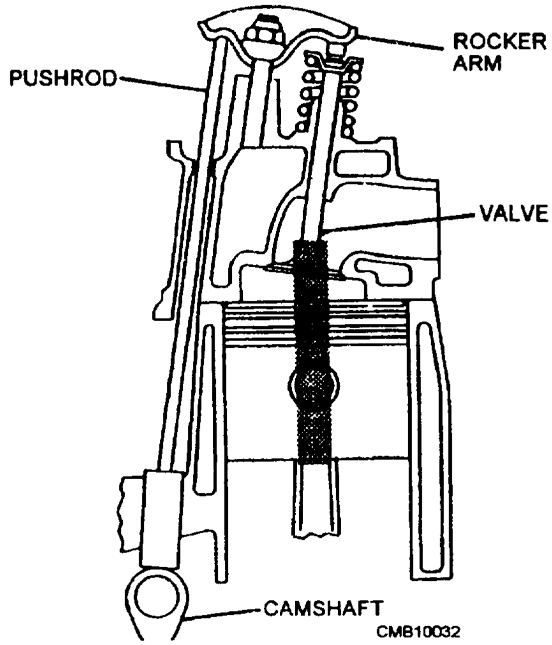


Figure 2-12.—I-head engine.

- **I-HEAD** (fig. 2-12)—The intake and the exhaust valves are both mounted in a cylinder head directly above the cylinder. This arrangement requires a tappet, a pushrod, and a rocker arm above the cylinder to reverse the direction of valve movement. Although this configuration is the most popular for current gasoline and diesel engines, it is rapidly being superseded by the overhead camshaft.

- **F-HEAD** (fig. 2-13)—The intake valves are normally located in the head, while the exhaust

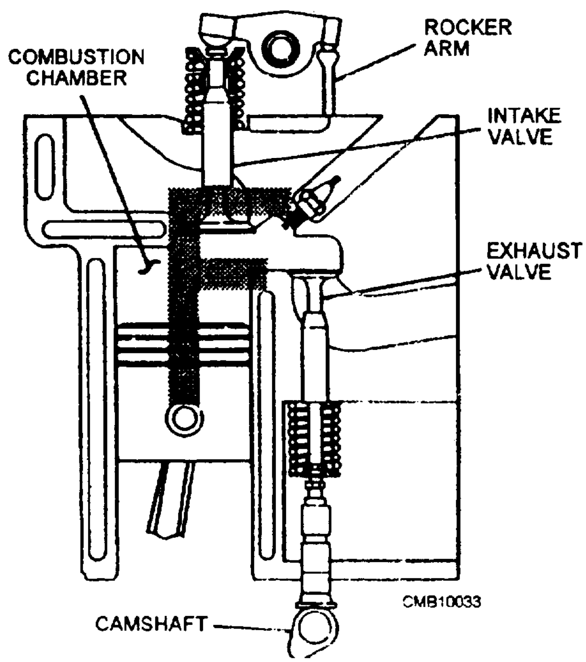


Figure 2-13.—F-head engine.

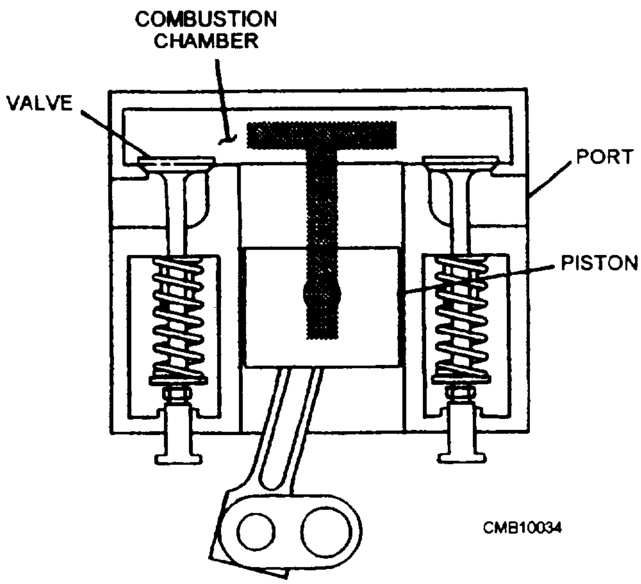


Figure 2-14.—T-head engine.

valves are located in the engine block. The intake valves in the head are actuated from the camshaft through tappets, pushrods, and rocker arms. The exhaust valves are actuated directly by tappets on the camshaft.

- **T-HEAD** (fig. 2-14)—The intake and the exhaust valves are located on opposite sides of the cylinder in the engine block, each requires their own camshaft.
- **SINGLE OVERHEAD CAMSHAFT** (fig. 2-15)—The camshaft is located in the cylinder head. The intake and the exhaust valves are both operated from a common camshaft. The valve train may be arranged to operate directly through the lifters, as shown in view A, or by rocker arms, as shown in view B. This configuration is becoming popular for passenger car gasoline engines.
- **DOUBLE OVERHEAD CAMSHAFT** (fig. 2-16)—When the double overhead camshaft is used, the intake and the exhaust valves each operate from separate camshafts directly through the lifters. It provides excellent engine performance and is used in more expensive automotive applications.

Q6. Other than construction, what three things differ in gasoline and diesel engines?

Q7. What type of cylinder arrangement is used when height is a consideration?

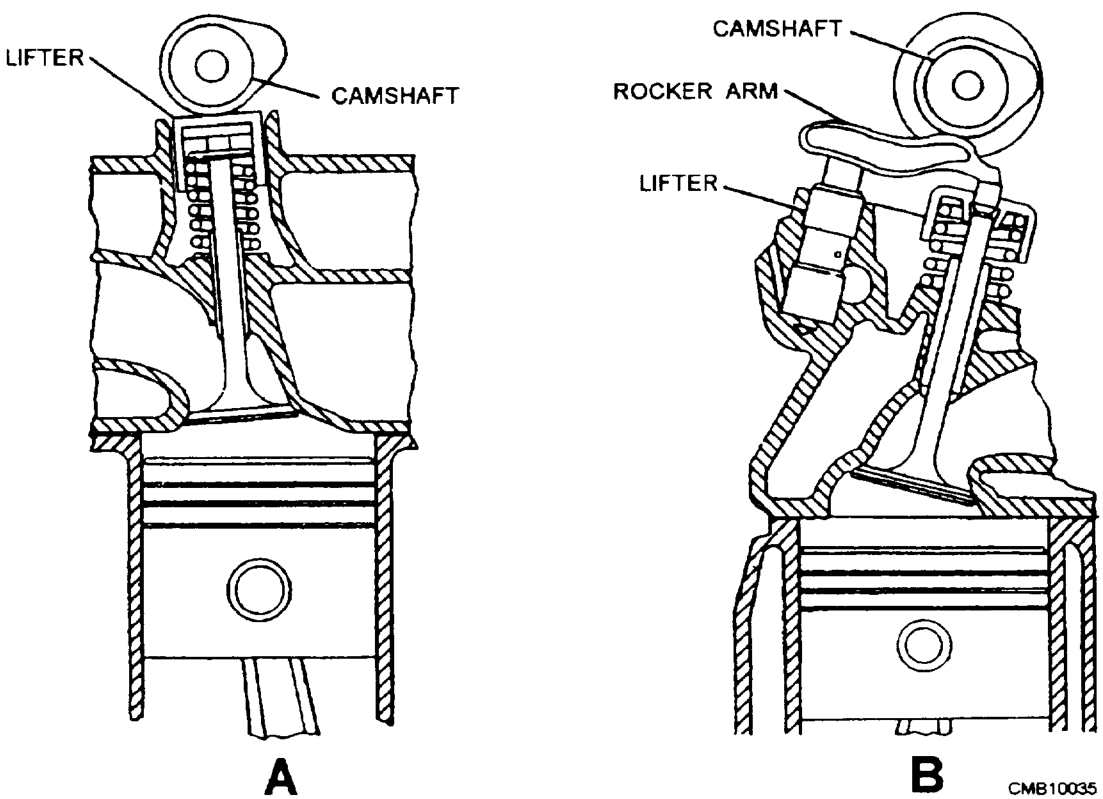


Figure 2-15.—Single overhead camshaft configurations.

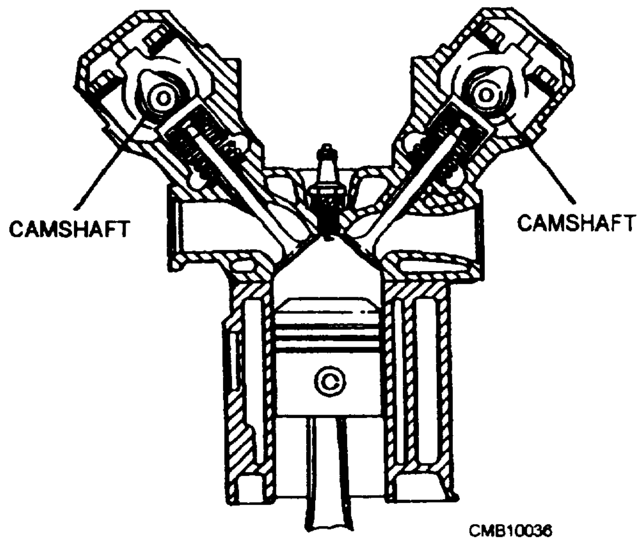


Figure 2-16.—Double overhead camshaft configuration.

Q8. In a horizontal-opposed engine, the cylinders are arranged at what number of degrees from each other?

Q9. What type of head design has the valves arranged directly over the cylinder?

Q10. What type of head design has exhaust valves located in the engine block?

ENGINE MEASUREMENTS AND PERFORMANCE

LEARNING OBJECTIVE: *Identify terms, engine measurements, and performance standards of an internal combustion engine.*

As a Construction Mechanic, you must know the various ways that engines and engine performance are measured. An engine may be measured in terms of cylinder diameter, piston stroke, and number of cylinders. It may be measured, performance wise, by the torque and horsepower it develops and by efficiency.

DEFINITIONS

WORK is the movement of a body against an opposing force. In the mechanical sense of the term, this is done when resistance is overcome by a force acting through a measured distance. Work is measured in units of foot-pounds. One foot-pound of work is equivalent to lifting a l-pound weight a distance of 1 foot (fig. 2-17). Work is always the force exerted over a distance. When there is no movement of an object, there is no work, regardless of how much force is exerted

ENERGY is the ability to do work. Energy takes many forms, such as heat, light, sound, stored energy (potential), or as an object in motion (kinetic energy). Energy performs work by changing from one form to another. Take the operation of an automobile for example; it does the following:

- When a car is sitting still and not running, it has potential energy stored in the gasoline.
- When a car is set in motion, the gasoline is burned, changing its potential energy into heat energy. The engine then transforms the heat energy into kinetic energy by forcing the car into motion.
- The action of stopping the car is accomplished by brakes. By the action of friction, the brakes transform kinetic energy back to heat energy. When all the kinetic energy is transformed into heat energy, the car stops.

POWER is the rate at which work is done. It takes more power to work rapidly than to work slowly. Engines are rated by the amount of work they can do per minute. An engine that does more work per minute than another is more powerful.

The work capacity of an engine is measured in **horsepower** (hp). Through testing, it was determined that an average horse can lift a 200-pound weight to a height of 165 feet in 1 minute. The equivalent of one horsepower can be reached by multiplying 165 feet by 200 pounds (work formula) for a total of 33,000 foot-

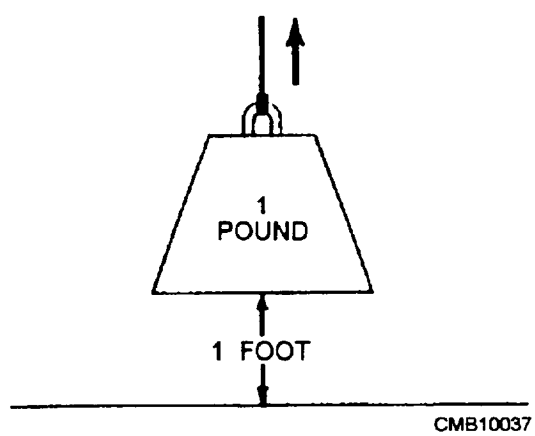


Figure 2-17.—One foot-pound of work.

pounds per minute (fig. 2-18). The formula for horsepower is the following:

$$Hp = \frac{\text{ft-lb. per min}}{33,000} = \frac{L \times W}{33,000 \times t}$$

L = length, in feet, through which W is moved

W = force, in pounds, that is exerted through distance L

T = time, in minutes, required to move W through L

A number of devices are used to measure the hp of an engine. The most common device is the dynamometer.

An **ENGINE DYNAMOMETER** (fig. 2-19) may be used to bench test an engine that has been removed from a vehicle. If the engine does not develop the recommended horsepower and torque of the manufacturer, you know further adjustments and/or repairs on the engine are required.

The **CHASSIS DYNAMOMETER** (fig. 2-19) is used for automotive service, since it can provide a quick report on engine conditions by measuring output at various speeds and loads. This type of machine is useful in shop testing and adjusting an automatic transmission. On a chassis dynamometer, the driving wheels of a vehicle are placed on rollers. By loading the rollers in varying amounts and by running the engine at different speeds, you can simulate many driving conditions. These tests and checks are made without interference by other noises, such as those that occur when you check the vehicle while driving on the road.

Another device that measures the actual usable horsepower of an engine is the **PRONY BRAKE** (fig. 2-20). It is used very little today, but is simple to understand. It is useful for learning the concept of horsepower-measuring tools. It consists of a flywheel surrounded by a large braking device. One end of an arm is attached to the braking device, while the other end exerts pressure on a scale. In operation, the engine is attached to, and drives, the flywheel. The braking device is tightened until the engine is slowed to a predetermined rpm. As the braking device slows the engine, the arm attached to it exerts pressure on a scale. Based on the reading at the scale and engine rpm, a brake horsepower valve is calculated by using the following formula:

$$\frac{6.28 \times \text{length of arm} \times \text{engine rpm} \times \text{scale reading}}{33,000}$$

It must be noted that 6.28 and 33,000 are constants in the formula, meaning they never change. For example, a given engine exerts a force of 300 pounds on a scale through a 2-foot-long arm when the brake device holds the speed of the engine at 3,000 rpm. By using the formula, calculate the brake horsepower as follows:

$$\frac{6.28 \times 2 \times 3000 \times 300}{33,000} = 342.55 \text{ brake horsepower}$$

TORQUE is a force that, when applied, tends to result in twisting an object, rather than its physical movement. When the torque is being measured, the force that is applied must be multiplied by the distance from the axis of the object. Torque is measured in pound-feet (not to be confused with work which is measured in foot-pounds). When torque is applied to an object, the force and distance from the axis depends on each other. For example, when 100 foot-pounds of torque is applied to a nut, it is equivalent to a 100-pound

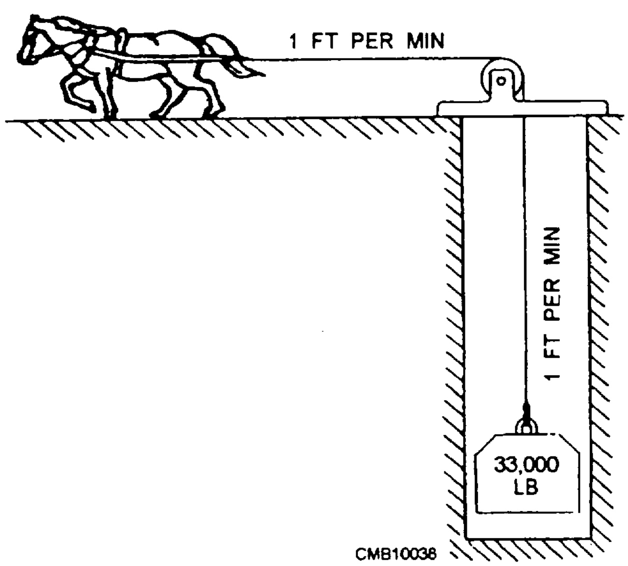


Figure 2-18.—Horsepower.

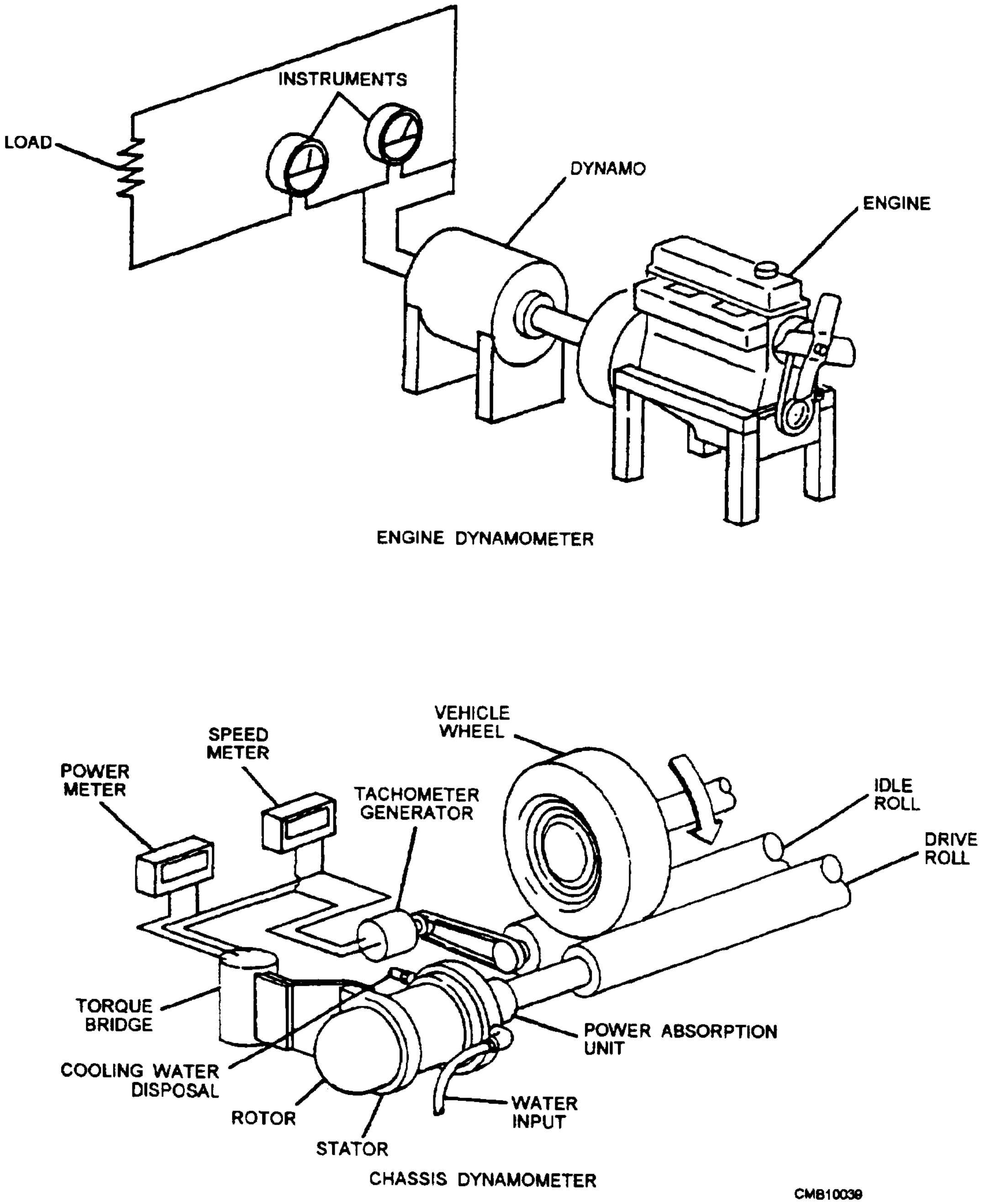


Figure 2-19.—Dynamometers.

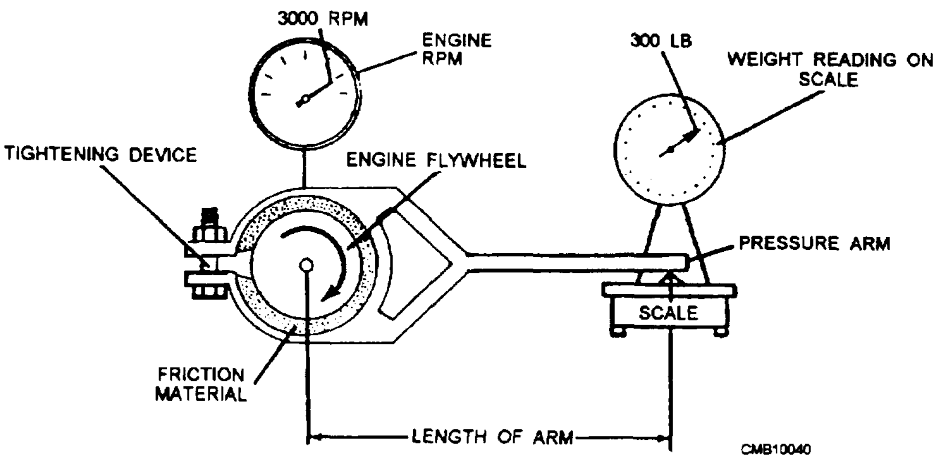


Figure 2-20.—Prony brake.

force being applied from a wrench that is l-foot long. When a 2-foot-long wrench is used, only a 50-pound force is required. An illustration of a torque wrench in use is shown in figure 2-21.

DO NOT confuse torque with work or with power. Both work and power indicate motion, but torque does not. It is merely a turning effort the engine applies to the wheels through gears and shafts.

ENGINE TORQUE is a rating of the turning force at the engine crankshaft. When combustion pressure pushes the piston down, a strong rotating force is applied to the crankshaft. This turning force is sent to the transmission or transaxle, drive line or drive lines, and drive wheels, moving the vehicle. Engine torque specifications are provided in a shop manual for a particular vehicle. One example, 78 pound-feet @ 3,000 (at 3,000) rpm is given for one particular engine. This engine is capable of producing 78 pound-feet of torque when operating at 3,000 revolutions per minute.

FRICTION is the resistance to motion between two objects in contact with each other. The reason a sled does not slide on bare earth is because of friction It slides on snow because snow offers little resistance, while the bare earth offers a great deal of resistance.

Friction is both desirable and undesirable in an automobile or any other vehicle. Friction in an engine is undesirable because it decreases the power output; in other words, it dissipates some of the energy the engine produces. This is overcome by using oil, so moving components in the engine slide or roll over each other smoothly. **Frictional horsepower** (fhp) is the power needed to overcome engine friction. It is a measure of resistance to movement between engine parts. Frictional horsepower is **POWER LOST** to friction. It reduces the amount of power left to propel a vehicle. Friction, however, is desirable in clutches and brakes, since friction is exactly what is needed for them to perform their function properly.

One other term you often encounter is **INERTIA.** Inertia is a characteristic of all material objects. It causes them to resist change in speed or direction of travel. A motionless object tends to remain at rest, and a moving object tends to keep moving at the same speed and in the same direction. A good example of inertia is the tendency of your automobile to keep moving even after you have removed your foot from the accelerator. You apply the brake to overcome the inertia of the automobile or its tendency to keep moving.

The term *efficiency* means the relationship between the actual and theoretical power output. **Volumetric efficiency** (fig. 2-22) is the ratio between the amount of air-fuel mixture that actually enters the cylinder and the amount that could enter under ideal conditions. The greater volumetric efficiency, the greater the amount of air-fuel mixture entering the cylinder; and the greater

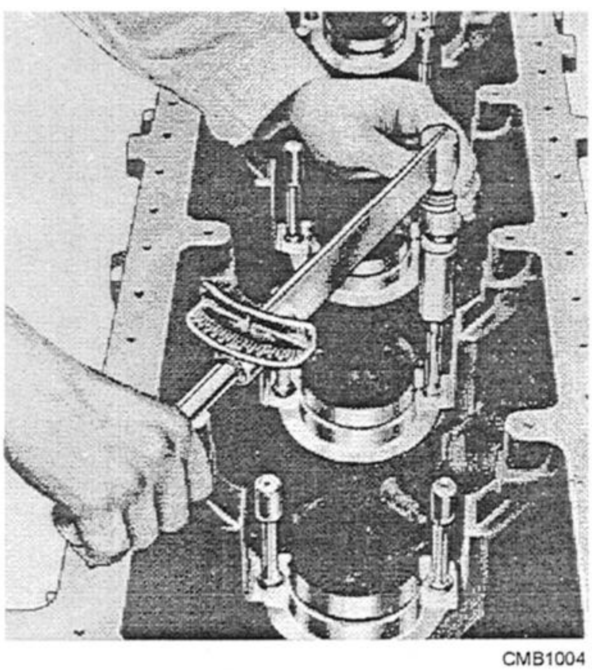
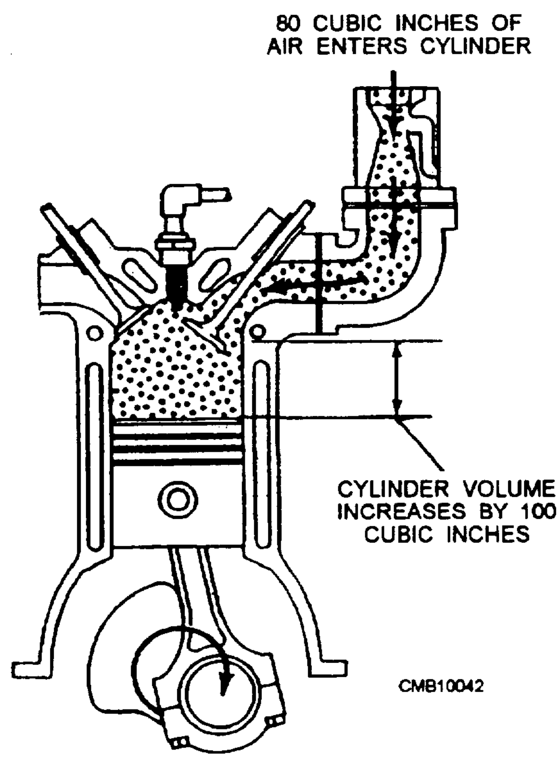


Figure 2-21.—Torque wrench in use, tightening main bearing stud of an engine.



Fire 2-22.—Demonstrating volumetric efficiency.

the amount of air-fuel mixture, the greater the power produced by the engine.

Increasing volumetric efficiency increases engine performance. Volumetric efficiency can be increasedin the following ways:

- Keep the intake mixture cool by ducting intake air from outside the engine compartment. By keeping the fuel cool, you can keep the intake mixture cooler. The cooler the mixture, the higher the volumetric efficiency. This is because a cool mixture is denser or more tightly packed.
- Modify the intake passages (fig. 2-23). Changes to the intake passages that make it easier for the mixture to flow through will increase the volumetric efficiency. Other changes include reshaping ports to smooth bends, reshaping the back of the valve heads, or polishing the inside of the ports.
- Altering the time that the valves open or how far they open can increase volumetric efficiency.
- By supercharging and turbocharging, you can bring the volumetric efficiency figures to over 100 percent.

MECHANICAL EFFICIENCY is the relationship between the actual power produced in the engine (indicated horsepower) and the actual power delivered at the crankshaft (brake horsepower). The actual power is always less than the power produced within the engine. This is due to the following:

- Friction losses between the many moving parts of the engine.
- In a four-stroke-cycle engine, a considerable amount of horsepower is used to drive the valve train.

From a mechanical efficiency standpoint, you can tell what percentage of power developed in the cylinder is actually delivered by the engine. The remaining percentage of power is consumed by friction, and it is computed as frictional horsepower (fhp).

THERMAL EFFICIENCY is the relationship between actual heat energy stored within the fuel and power produced in the engine (indicated horsepower). The thermal efficiency figure indicates the amount of potential energy contained in the fuel that is actually used by the engine to produce power and what amount of energy is actually lost through heat. A large amount of energy from the fuel is lost through heat and not used in an internal combustion engine. This unused heat is of no value to the engine and must be removed from it. Heat is dissipated in the following ways:

- The cooling system removes heat from the engine to control engine operating temperature.
- A major portion of the heat produced by the engine exits through the exhaust system.
- The engine radiates a portion of the heat to the atmosphere.

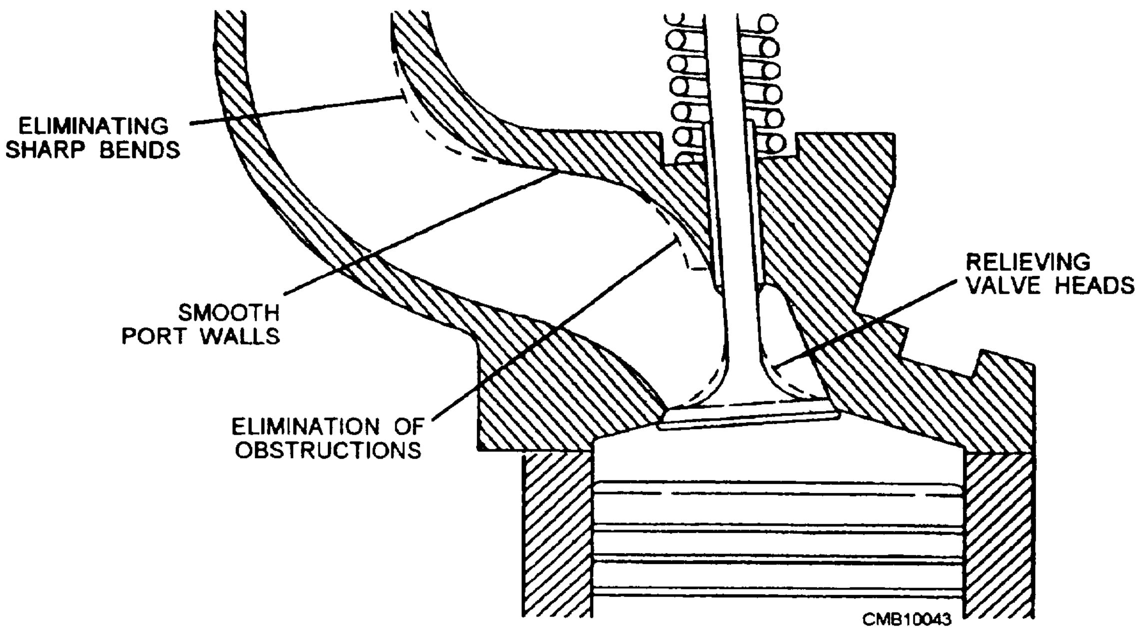


Figure 2-23.—Port design consideration.

- A portion of this waste heat may be channeled to the passenger compartment to heat it.
- The lubricating oil in the engine removes a portion of the waste heat.

In addition to energy lost through waste heat, there are the following inherent losses in the piston engine.

- Much energy is consumed when the piston must compress the mixture on the compression stroke.
- Energy from the fuel is consumed to pull the intake mixture into the cylinder.
- Energy from the fuel is consumed to push the exhaust gases out of the cylinder.

The combination of all these factors in a piston engine that uses and wastes energy leaves the average engine approximately 20 to 25 percent thermally efficient.

LINEAR MEASUREMENTS

The size of an engine cylinder is indicated in terms of bore and stroke (fig. 2-24). **BORE** is the inside diameter of the cylinder. **STROKE** is the distance between top dead center (TDC) and bottom dead center (BDC). The bore is always mentioned first. For example, a 3 1/2 by 4 cylinder means that the cylinder bore, or diameter, is 3 1/2 inches and the length of the stroke is 4 inches. These measurements are used to figure displacement.

PISTON DISPLACEMENT is the volume of space that the pistondisplaces, as it moves from one end of the stroke to the other. Thus the piston displacement in a 3 1/2-inch by 4-inch cylinder would be the area of a 3 1/2-inch circle multiplied by 4 (the length of the stroke.) The area of a circle is πR^2, where R is the radius (one half of the diameter) of the circle. With S being the length of the stroke, the formula for volume (V) is the following:

$V = \pi R^2 \times S$

If the formula is applied to figure 2-22, the piston displacement is computed as follows:

R = 1/2 the diameter = 1/2 x 3.5 = 1.75 in.

$\pi = 3.14$

$V = \pi (1.75)^2 \times 4$

V = 3.14 x 3.06 x 4

V = 38.43 cu in.

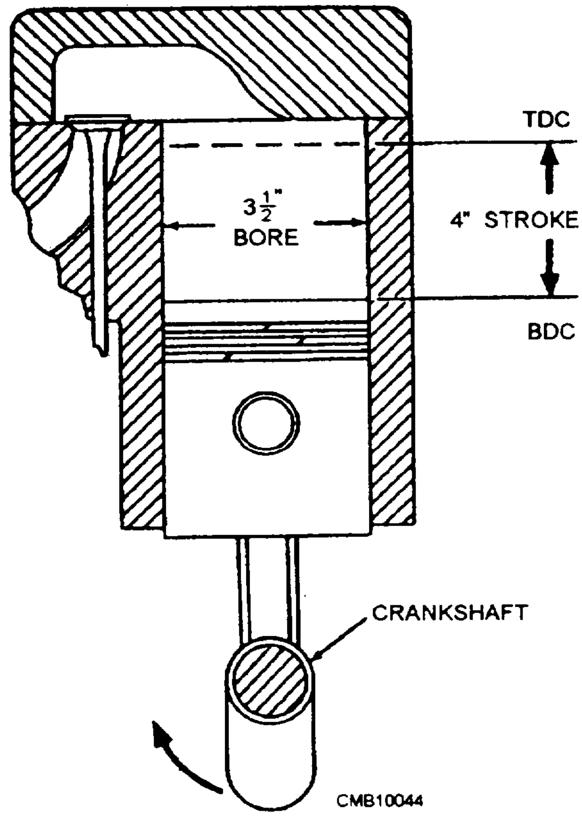


Figure 2-24.—Bore and stroke of an engine cylinder.

The total displacement of an engine is found by multiplying the volume of one cylinder by the total number of cylinders.

38.43 cu in. x 8 cylinders = 307.44 cu in.

The displacement of the engine is expressed as 307 cubic inches in the English system. To express the displacement of the engine in the metric system, convert cubic inches to cubic centimeters. This is done by multiplying cubic inches by 16.39. It must be noted that 16.39 is constant.

307.44 cu in. x 16.39 = 5,038.9416 cc

To convert cubic centimeters into liters, divide the cubic centimeters by 1,000. This is because 1 liter = 1,000 cc.

$$\frac{5{,}038.9416}{1{,}000} = 5.0389416$$

The displacement of the engine is expressed as 5.0 liters in the metric system.

ENGINE PERFORMANCE

The **COMPRESSION RATIO** of an engine is a measurement of how much the air-fuel charge is compressed in the engine cylinder. It is calculated by dividing the volume of one cylinder with the piston at BDC by the volume with the piston TDC (fig. 2-25). One should note that the volume in the cylinder at TDC is called the clearance volume.

For example. suppose that an engine cylinder has a volume of 80 cubic inches with the piston at BDC and a volume of 10 cubic inches with the piston at TDC. The compression ratio in this cylinder is 8 to 1, determined by dividing 80 cubic inches by 10 cubic inches; that is, the air-fuel mixture is compressed from 80 to 10 cubic inches or to one eighth of its original volume.

Two major advantages of increasing compression ratio are that power and economy of the engine improve without added weight or size. The improvements come about because with higher compression ratio the air-fuel mixture is squeezed more. This means a higher initial pressure at the start of the power stroke. As a result. there is more force on the piston for a greater part of the power stroke; therefore, more power is obtained from each power stroke.

Increasing the compression ratio, however, brings up some problems. Fuel can withstand only a certain amount of squeezing without knocking. Knocking is the sudden burning of the air-fuel mixture that causes a quick increase in pressure and a rapping or knocking noise,. The fuel chemists have overcome knocking by creating antiknock fuels. (Antiknock fuels are described in a later module).

Oxygen must be present if combustionis to occur in the cylinder, and since air is the source of the supply of oxygen used in engines, the problem arises of getting the proper amount of air to support combustion. This factor is known as the **AIR-FUEL RATIO.** Agasoline engine normally operates at intermediate speeds on a 15 to 1 ratio; that is, 15 pounds of air to 1 pound of gasoline.

TIMING

In a gasoline engine, the valves must open and close at the proper times with regard to piston position and stroke. In addition, the ignition system must produce sparks at the proper time, so power strokes can start. Both valve and ignition system action must he timed properly to obtain good engine performance.

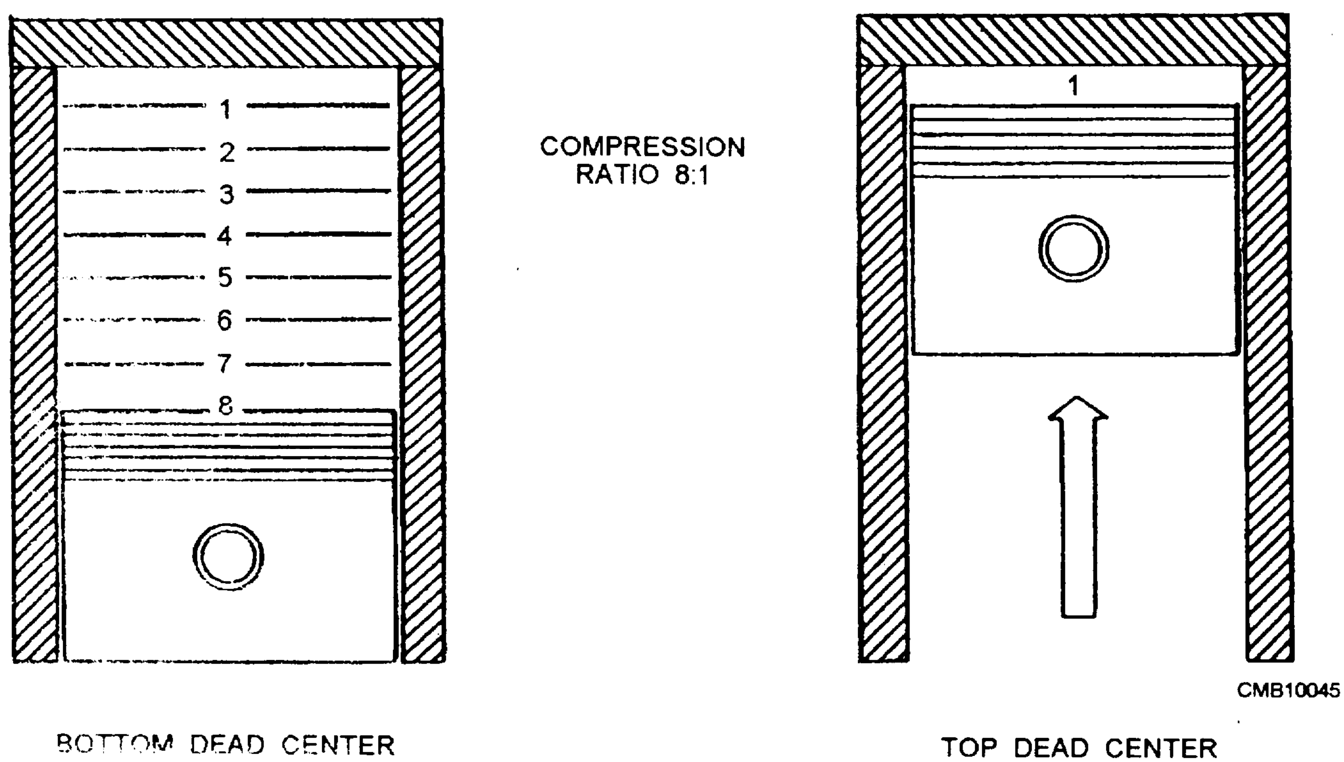


Figure 2-25.—Compression ratio.

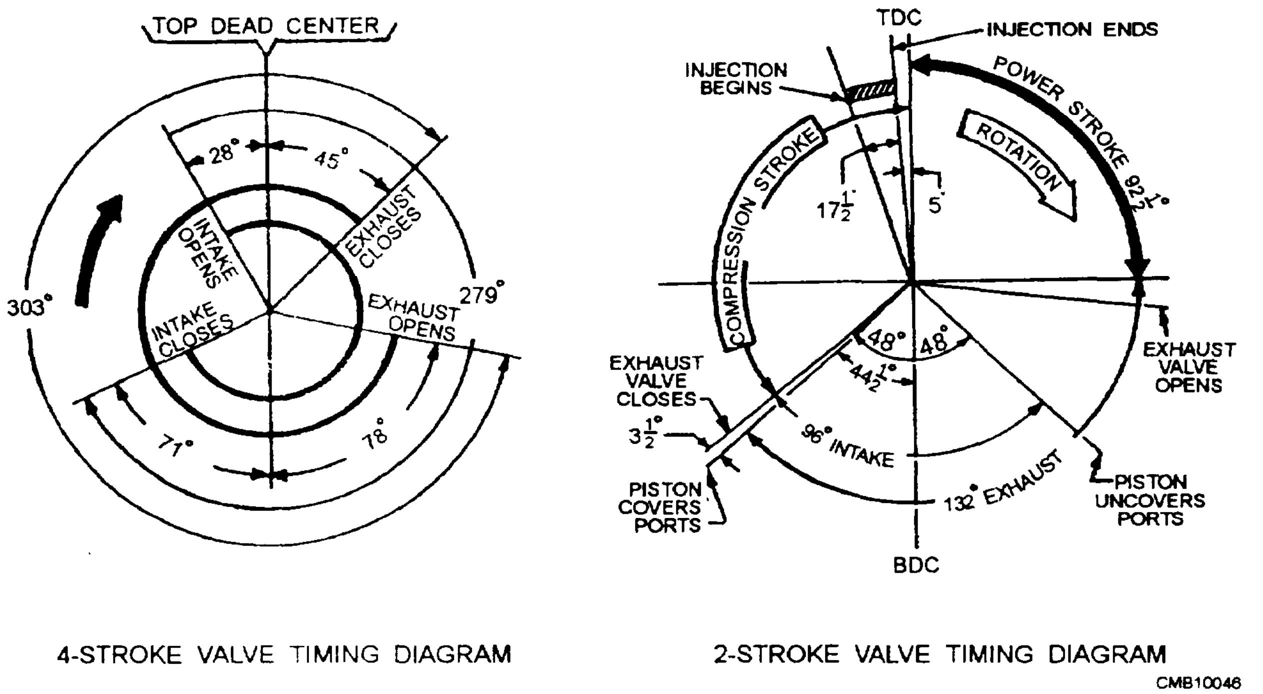


Figure 2-26.—Typical valve timing diagrams.

VALVE TIMING (fig. 2-26) is a system developed for measuring valve operation in relation to crankshaft position (in degrees), particularly the points when the valves open, how long they remain open, and when they close. Valve timing is probably the single most important factor in tailoring an engine for special needs. An engine can be made to produce its maximum power in various speed ranges by altering valve timing. The following factors together make up a valve operating sequence:

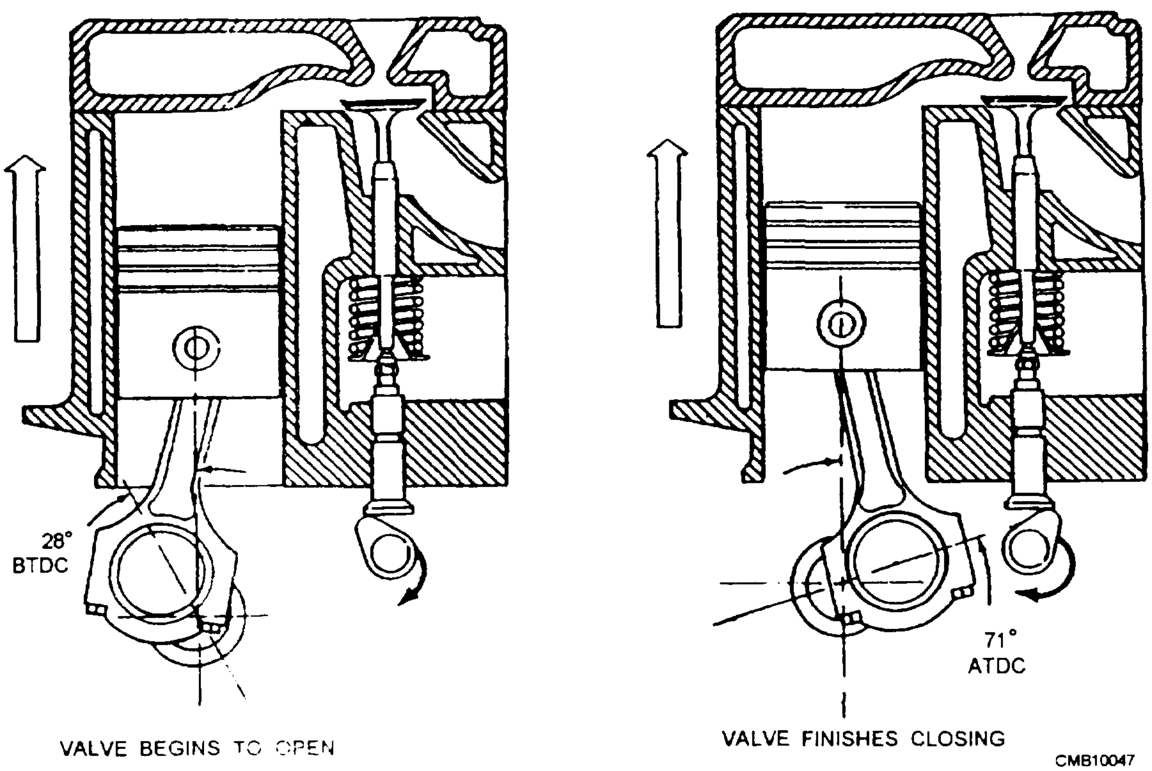


Figure 2-27.—Opening and closing points of the valve.

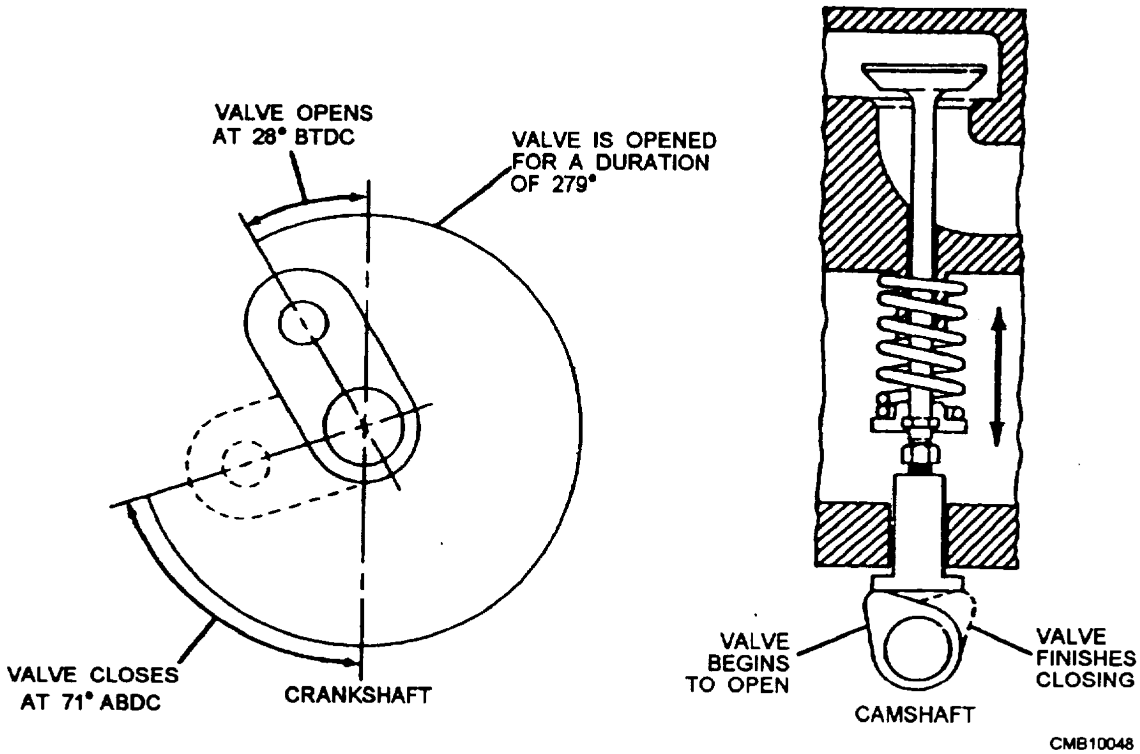


Figure 2-28.—Valve opening duration.

1. The opening and closing points (fig. 2-27) are positions of the crankshaft (in degrees) when the valves just begin to open and just finish closing.

2. Duration (fig. 2-28) is the amount of crankshaft rotation (in degrees) that a given valve remains open.

3. Valve overlap (fig. 2-29) is a period in a four-stroke cycle when the intake valve opens before the exhaust valve closes.

4. Valve timing considerations, throughout the crankshaft revolution, the speed of the piston changes. From a stop at the bottom of the stroke, the piston reaches its maximum speed halfway through the stroke and gradually slows to a stop as it reaches the end of the stroke. The piston behaves exactly the same on the downstroke. One of these periods begins at approximately 15 to 20 degrees before top dead center (BTDC) and ends at approximately 15 to 20 degrees

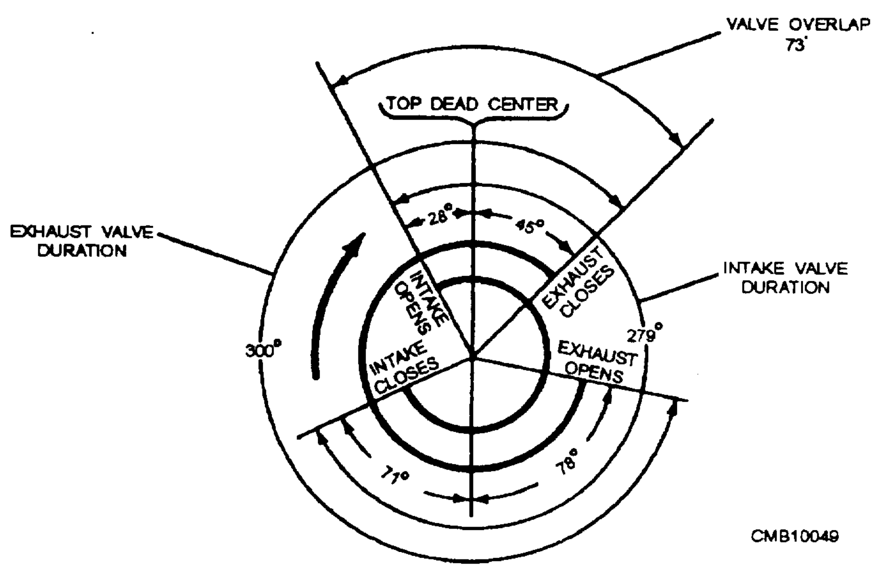


Figure 2-29.—Valve timing diagram showing valve overlap,

after top dead center (ATDC). The other period begins approximately 15 to 20 degrees before bottom dead center (BBDC) and ends approximately 15 to 20 degrees after bottom dead center (ABDC). These two positions are shown in figure 2-30. These positions are commonly referred to as **ROCK POSITIONS**

IGNITION TIMING (fig. 2-31) refers to the timing of the spark plug firing with relation to the piston position during compression and power strokes. The ignition system is timed, so the spark occurs before the piston reaches TDC on the compression stroke. This gives the mixture enough time to ignite and start burning.

If this time were not provided—that is, if spark occurred at or after TDC—then the pressure increases would take place too late to provide a full-power stroke.

In figure 2-31, view A, the spark occurs at 10 degrees before top dead center; view B, the spark occurs at top dead center; and view C, the spark occurs at 10 degrees after top dead center.

At higher speeds, there is still less time for the air-fuel mixture to ignite and burn. The ignition system includes both the vacuum and mechanical advance mechanisms that alter ignition timing to compensate for this and avoid power loss, as engine speeds increases.

Q11. One foot-pound of work is equivalent to lifting I pound what distance?

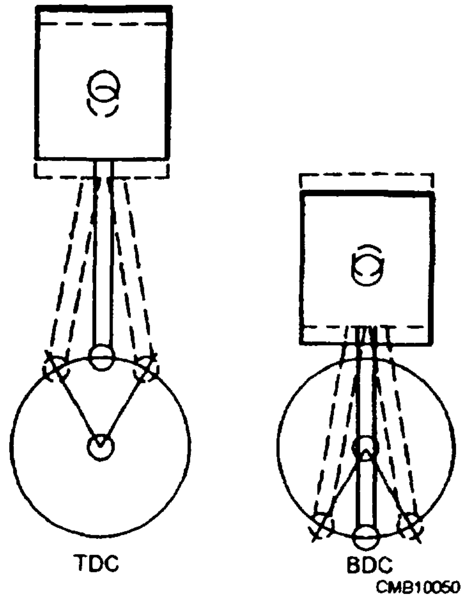


Figure 2-30.—Rock position.

Q12. What device uses a flywheel to measure actual usable horsepower?

Q13. What term is used for resistance to motion?

Q14. The relationship between actual power produced by an engine and actual power delivered to the crankshaft is known by what term?

Q15. What metric unit of measurement is used to express engine displacement?

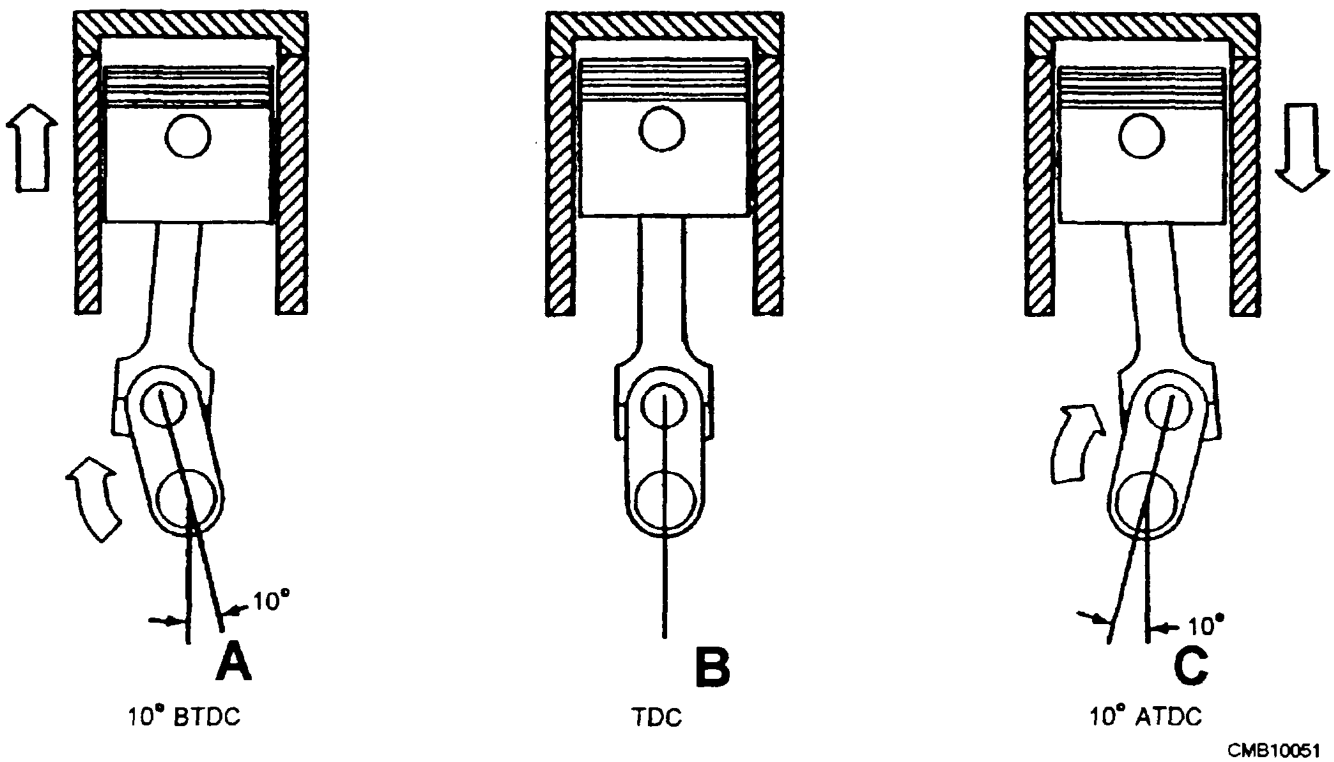


Figure 2-31.—Ignition timing.